

EXPERIMENTAL STUDY ON STRENGTH & DEFORMATION BEHAVIOUR OF SLABS WITH OPENINGS

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ABSTRACT

A concrete slab is a common structural element of modern buildings. Horizontal slabs of steel reinforced concrete, typically between 100 and 500 millimeters thick, are most often used to construct floors and ceilings, while thinner slabs are also used for exterior paving. Slabs, in definition and the way of designing them, are structures that transmit loads normal to their plane. Concrete slabs are widely in use as floors not only in industrial and residential buildings but also as decks in bridges. The big advantage is flexibility in methods of manufacturing. They can be made in-situ as well as prefabricated and brought to construction site in full scale. For larger spans pre-stressed concrete is very often applied to increase capacity without extending slab height.

Openings in slabs are usually required for plumbing, fire protection pipes, heat and ventilation ducts and air conditioning. Larger openings that could amount to the elimination of a large area within a slab panel are sometimes required for stairs and elevators shafts, improving air circulation, lighting arrangement in multi-storey buildings, aesthetics etc. They also ensure full utilization of the building parts that would otherwise be cut off from natural light supply. However, these openings pose a break in the continuity of the slab causing weak points in the whole structure. They thus require special attention in analysis and design. They also limit the capacity of the slab to control the spread of fire. The structural effect for small openings is often not considered due to the ability of the structure to redistributed stresses. However, for large openings, the static system may be altered when it involves a significant amount of concrete and reinforcement bar that need to be removed. This may lead to decrease in ability of the structure to withstand the imposed loads and the structure needs.

KEYWORDS: Common Structural Element, Industrial Buildings, Prefabricated, Weak Points, Natural Light Supply

INTRODUCTION

American concrete institute (ACI) has given some guidelines about the position and size of permissible openings, and the additional reinforcement requirements, but there is no theoretical background for these guidelines.

As an alternative to detailed analysis for slabs with openings, ACI 318-05 gives the following guidelines for opening size in different locations for flat plates and flat slabs. These guidelines are illustrated in Figure 1 for slabs with:

- In the area common to intersecting middle strips, openings of any size are permitted (Section 13.4.2.1);
- In the area common to intersecting column strips, the maximum permitted opening size is 1/8 the width of the column strip in either span (Section 13.4.2.2); and

- In the area common to one column strip and one middle strip, the maximum permitted opening size is limited such that only a maximum of 1/4 of the slab reinforcement in either strip may be interrupted (Section 13.4.2.3).

To apply this simplified approach, ACI 318-05 requires that the total amount of reinforcement calculated for the panel without openings, in both directions, must be maintained; thus, half of the reinforcement interrupted must be replaced on each side of the opening. In addition to flexural requirements, the reduction in slab shear strength must also be considered when the opening is located anywhere within a column strip of a flat slab or within 10 times the slab thickness from a concentrated load or reaction area. Moreover, these guidelines are for flat slabs only, there is nothing about where and of which size openings should be permissible in slabs resting on beams, and this is why we are doing this experimental study.

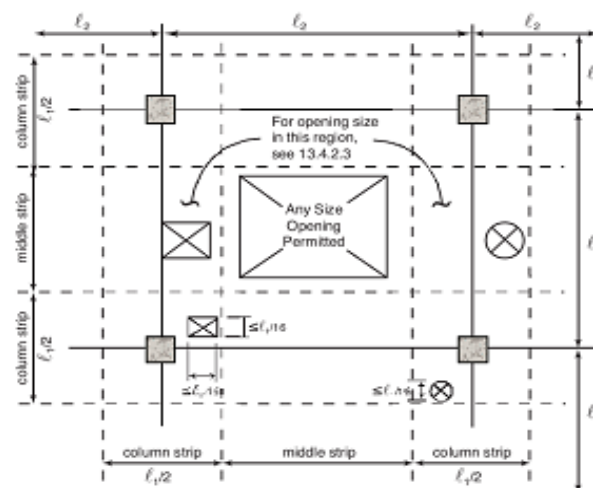


Figure 1: Illustration of ACI 318-05 Guidelines

OBJECTIVES OF THE STUDY

Due to the difficulty of theoretical analysis of reinforced concrete slabs especially when there is an opening in these slabs, the experimental investigation is still an efficient method to explore their behaviour. An experimental study for these slabs can overcome this difficulty and give a correct expectation about the behaviour of similar slabs. This paper presents an experimental study on the behaviour of slabs containing openings at different locations and of different sizes.

The main objectives of this experimental study are:

- To check the decrease in flexural strength of slabs having openings from the one without opening.
- To compare the relative change in flexural strength of slab panels with openings at different locations.
- To compare the relative change in flexural strength of slab panels with openings of different sizes.
- To compare the test results of all the slab panels having openings with the modal panel without opening.
- To see whether there is any other type of failure before flexure, in any of the panels.

EXPERIMENTAL PROGRAM

Ten panels of size 1m*1m each were casted for the present study. One of the slab panels is treated as modal panel (control panel) with no opening, with which all the comparisons are to be made. The other nine panels were classified into three groups. These groups are simply named as GROUP1, GROUP2 and GROUP3.

Group1

This group contains three slab panels. First having central square opening of size 0.2m*0.2m and named G1-O>20. Second having central square opening of size 0.3m*0.3m and named G1-O>30. Third having central square opening of size 0.4m*0.4m and named G1-O>40.

Group2

This group contains three slab panels. First having corner square opening of size 0.2m*0.2m and named G2-O>20. Second having corner square opening of size 0.3m*0.3m and named G2-O>30. Third having corner square opening of size 0.4m*0.4m and named G2-O>40.

Group3

This group contains three slab panels. First having edge square opening of size 0.2m*0.2m and named G3-O>20. Second having edge square opening of size 0.3m*0.3m and named G3-O>30. Third having edge square opening of size 0.4m*0.4m and named G3-O>40.

PROPERTIES OF THE USED MATERIALS

Aggregates

- Gravel: Well graded crushed gravel of nominal size 10 mm and 20mm was used for casting all specimens.
- Sand: Well graded, clean, free of organic matters and any other impurities sand was used.
- Cement

Ordinary Portland cement complied of grade 43 was used.

Steel Reinforcement

High strength steel bars of 8mm dia were used for all slab panels. The yield strength f_y of the bars was equal to 415 N/mm².

Water

Clean water was used in all mixes, to give water cement ratio w/c 0.5.

CONCRETE MIX PROPORTIONS

The concrete mixes used in casting all specimens had the mix proportion (by weight) shown in table 1. Materials used to produce one cubic meter of concrete are given in table 2.

Table 1: Concrete Mix Proportions by Weight

Cement	Sand	Gravel	W/C
1	1.5	3	0.5

Table 2: Materials Used for 1.0m³

Cement	Sand	Gravel	W/C
410 kg	615 kg	1230 kg	205 Lit.

During the casting of slabs cubes, as suggested by IS 456:2000, were also casted to know the exact strength of concrete. The cubes were tested in a UTM and the results were recorded after 7 days and 28 days. The final results were in the range M20-M25. The average strength of the concrete slabs was 23.1 N/mm².

TESTING PROCEDURE

All plate models were tested using the steel frame supported on four edge supports. The supports were plate girders of flange width 100mm each. Each plate model was loaded up to failure using the steel frame applying the load by a hydraulic jack. The load increments were achieved by increasing hydraulic jack compression, each load increment was made till 150 intervals of proving ring. After each load increment deflections were recorded.

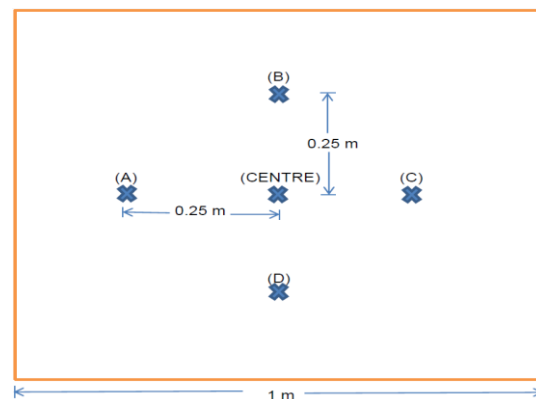


Figure 2: Position of Dial Gauges

First cracking loads and failure loads were recorded, also cracks propagation were marked. Five points were selected to record deflections and dial gauges were fixed at these points. The arrangement/position of dial gauges is given in Figure 2. An image of testing arrangement is also given in Figure 3. Loading applied was of uniformly distributed load type, and produced by plate girders as in grillage foundation.



Figure 3: Image of Testing Arrangement

MAXIMUM LOAD CARRYING CAPACITY (IS 456: 2000)

The modal panel is a square of 1m side, the thickness of the panels was kept 60mm. We provided eight 8mm HYSD dia bars in both the directions with a clear cover of 10mm.

Concrete M-25 Steel Fe-415

Thickness of slab = 60 mm

Effective cover = $10 + 4 = 14$ mm.

Effective depth = $60 - 14 = 44$ mm

Total Sectional Area = $1000 \times 46 = 46000$ Mm².

Total Steel Area = $8 \times d^2/4$.

= 402 Mm².

Percentage Of Steel $P_t = 0.87\%$.

For M20 And Fe-415 And $P_t = 0.87\%$ $R_u = 2.58$. (SP-16)

Now $R_u = M_u / B d^2$

M_u = Ultimate bending moment.

B = Breadth of slab.

$M_u = 5459280$ Nmm

Now From Annexure D (Clause 2.1) Of Is 456: 2000

$M_x = \alpha_x w l_x^2$

Where: M_x = Moment in x direction. α_x = Moment coefficient.

$w = M_x / \alpha_x l_x^2$

$w = 88052903$ N/mm²

Maximum load carrying capacity = 88 kN/m².

DIMENSIONS AND REINFORCEMENT OF TESTED PLATES

Eight bars of 8mm diameter in bottom in each direction were used in all tested slabs. The typical dimensions and reinforcement arrangement of the modal panel and of the three tested groups are shown Figures 4 to 7.



Figure 4: Reinforcement Image of Modal Panel



Figure 5: Reinforcement Image of Panels of Group1 (G1- O>30)



Figure 6: Reinforcement Image of Panels of Group2 (G2-O>3)



Figure 7: Reinforcement Image of Panels of Group3 (G3-O>30)

DISCUSSION OF RESULTS

The test results of the ten slab models are presented and discussed on the basis of comparison of load-deflections relationships. Comparisons made between the slab panels are made systematically. Firstly a comparison is made between the slab panels of different groups with modal panel. Then a comparison is made between the slab panels of GROUP2 with GROUP1. Then a comparison is made between the slab panels of GROUP3 with GROUP2 and GROUP3 with GROUP1. Finally a comparison is made between all the slab panels of all the groups with modal panel.

Figure below shows comparison between the load-deflection relationship for slab models of GROUP1 having square openings at centre with the modal panel without any opening at point B in the slab. This comparison indicates that the deflection values recorded at the same load for different slabs gives greater values for slabs with openings. And further the bigger the opening dimension the greater the deflection values at a same load. One more thing noticed is that the deflections of the slabs of GROUP1 were same till loads closer to that of loads at development of first crack.

RESULTS OF MODAL PANEL

The experimental results of the modal panel are shown in a tabular form. The deflections for the corresponding loads are shown in the table below. Failure load is shown below the table.

Table 1

Load In kN/m^2	Deflection In Mm				
	Centre Location	Location A	Location B	Location C	Location D
2.1	0.39	0.13	0.17	0.31	0.31
32.5	0.63	0.37	0.50	0.63	0.62
53.0	0.89	0.57	0.71	1.10	0.93
73.5	1.67	0.83	1.20	1.41	1.29
94.0	2.21	1.30	1.81	1.53	2.01
114.5	2.67	1.57	2.21	1.90	2.53
135.0	3.43	2.13	2.81	2.67	3.33
155.5	4.45	3.57	3.71	3.83	4.21
176.0	5.51	4.21	4.31	4.47	4.59
196.5	6.31	5.19	5.27	5.41	5.67
217.0	8.11	6.21	6.31	6.71	6.41
237.5	9.91	7.45	7.11	7.89	7.63
258.0	12.37	8.20	8.90	8.93	9.21

Failure load: 258 kN/m^2

Development of first crack: 114.5 kN/m^2



Figure 8: Development of First Cracks



Figure 9: Crack Pattern of the Modal Panel

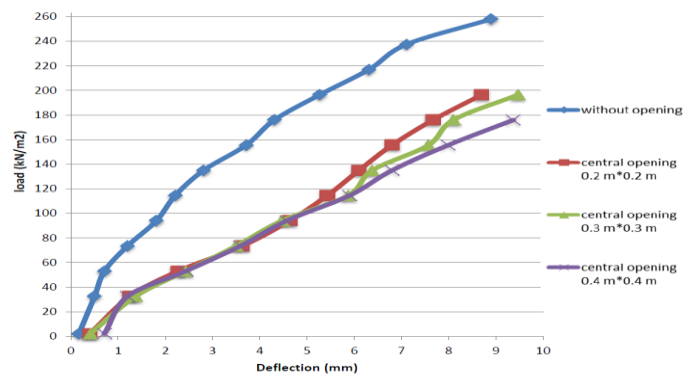


Figure 10: Comparison of Load-Deflection Relationship for Slab GROUP1 with Modal Panel at Point B

Similarly the data was collected from the testing of slab panels of other groups & their load vs deflection curves were plotted.

CRACK PATTERN

The cracks were observed first at a total load of (85.8 kN/m²) for slab G1-O>20, at a total load of (73.5 kN/m²) for slab G1-O>30 and at a total load of (61.2 kN/m²) for slab G1-O>40. The failure loads for this group were (217.5 kN/m²), (196.5 kN/m²) and (176 kN/m²) kg for slabs G1-O>20, G1-O>30 and G1-O>40 respectively. The last cracks appearing just before failure were the diagonal cracks near the corner supports.

FAILURE LOADS

Table below shows the comparison of first crack development and failure load of the slab panels of GROUP1 with the modal panel. With 4% decrease in modal area (area of modal panel) the load carrying capacity reduces by 16%, with 9% decrease in modal area the load carrying capacity reduces by 28% and with 16% decrease in modal area the load carrying capacity reduces by 32 %.

Table 2

Slab Panel	First Crack (kN/m ²)	Failure Load (kN/m ²)
Modal Panel	114.5	258
G1-O>20	85.8	217.5
G1-O>30	73.5	186.5
G1-O>40	61.2	176
G2-O>20	84.8	196.5
G2-O>30	73.5	155.5
G2-O>40	53.2	75.7

Table 2: Contd.,		
G3-O>20	85.8	217
G3-O>30	73.5	196.5
G3-O>40	71.2	176

COMPARISON OF LOAD-DEFLECTION RELATIONSHIP

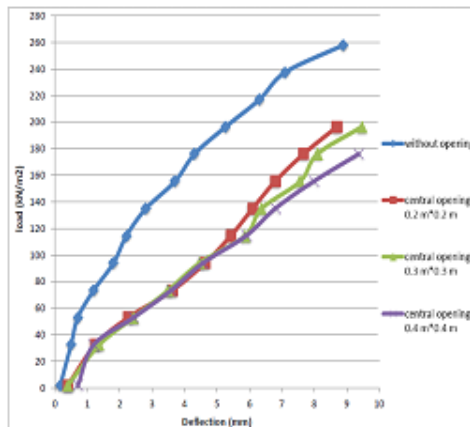


Figure 11: Comparison of Load-Deflection Relationship for Slab Group 1 with Modal Panel at Point B

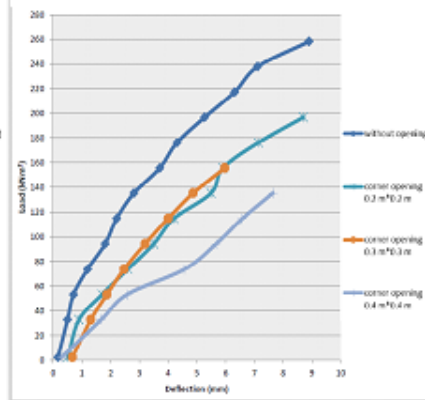


Figure 12: Comparison of Load-Deflection Relationship for Slab Group 2 with Modal Panel at Point B

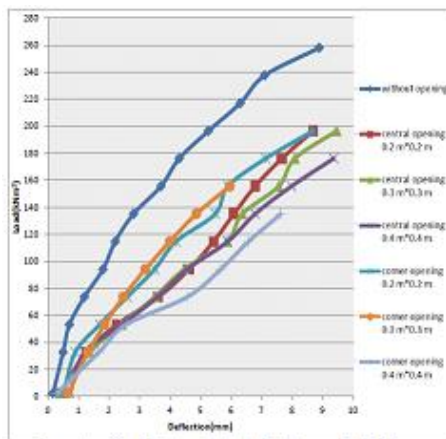


Figure 13: Comparison of Load-Deflection Relationship for Slab Group 2 with Slab Group 1 at Point B

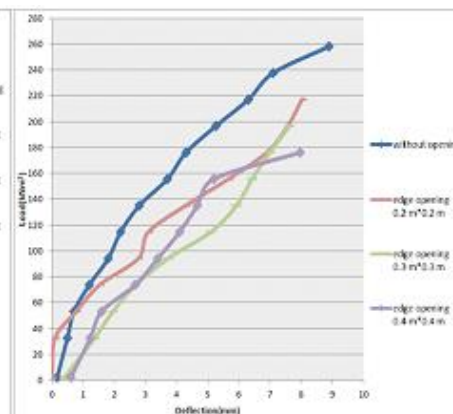


Figure 14: Comparison of Load-Deflection Relationship for Slab Group 3 with Modal Panel at Point B

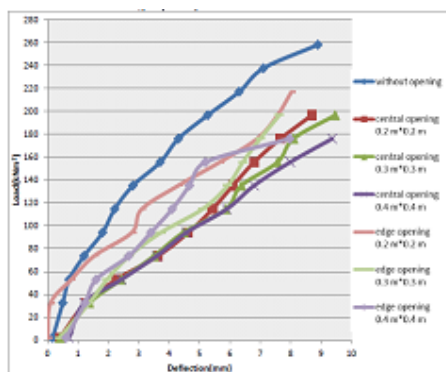


Figure 15: Comparison of Load-Deflection Relationship for Slab Group 3 with Slab Group 1 at Point B

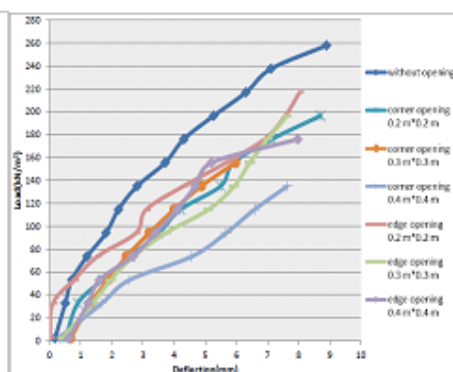


Figure 16: Comparison of Load-Deflection Relationship for Slab Group 3 with Slab Group 2 at Point B

CONCLUSIONS

From this experimental work and its results the following conclusions can be drawn:

- The presence of openings in flat slabs decreases the strength and rigidity of the flat slabs depending on the sizes, and locations of these openings.
- The bigger the dimension of the opening, the higher the deflection values at any point in the slab for the same loading.
- The deflection increases at the positions which are close to the openings, and decreases in the positions which are far from openings and continue in decreasing gradually.
- Deflections shown by slab panels having corner openings are larger as compared with slab panels having central and edge openings of same size and at same load.
- With 4% decrease in modal area the load carrying capacity reduces by about 16%, with 9% decrease in modal area the load carrying capacity reduces by 28% and with 16% decrease in modal area the load carrying capacity reduces by 32 %.
- The carrying capacities of slabs with corner openings decreased to 90% of those with central openings and edge openings of the same sizes. Hence the most preferable location for any size opening is away from the corner supports.
- Slabs having central and edge opening serve failure requirements better than openings at other locations.
- Slabs having corner openings serve serviceability requirements better than openings at other locations.
- Slabs having central openings fail under flexure, Slabs having corner openings fail under shear before flexure and Slabs having edge openings fail almost together in both flexure and shear.

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